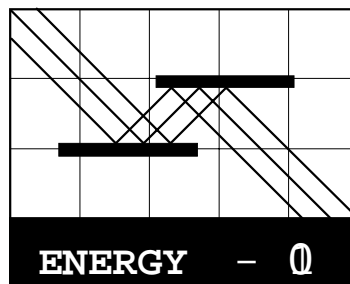> # *ENERGY-10:*
> # *A* Design-Tool Computer Program
> # for Efficient Houses

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ENERGY — 10

ENERGY-10:
A Design-Tool Computer Program for Efficient Houses

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ABSTRACT

ENERGY-10 is a PC-based building energy simulation program for buildings that is specifically designed to evaluate energy-efficient features in the very early stages of the design process. It is applicable to residential, smaller commercial, and institutional buildings. Developed specifically as a design tool, the program makes it easy to evaluate the integration of improved levels of insulation, passive solar design, low-energy cooling, and energy-efficient equipment into high-performance buildings. The simulation engines perform whole-building energy analysis for 8760 hours per year including both daylighting and dynamic thermal calculations. The primary target audience for the program is building designers, especially builders and architects, but also includes HVAC engineers, utility officials, and architecture and engineering students and professors.

THE NEED FOR A NEW KIND OF DESIGN TOOL

More than 20 years of experience in the design of energy-efficient buildings has taught us several lessons:

(1) Proper evaluation of options is a complex process involving trade-offs of many issues. Accounting for all the important effects requires a detailed hour-by-hour simulation. For example, the program should be capable of simultaneously evaluating daylighting, the thermal effects of the reduced lighting loads, and the resulting HVAC and time-of-day effects on demand charges. Without this capability, the interactions between heating, cooling, and daylighting cannot be understood.
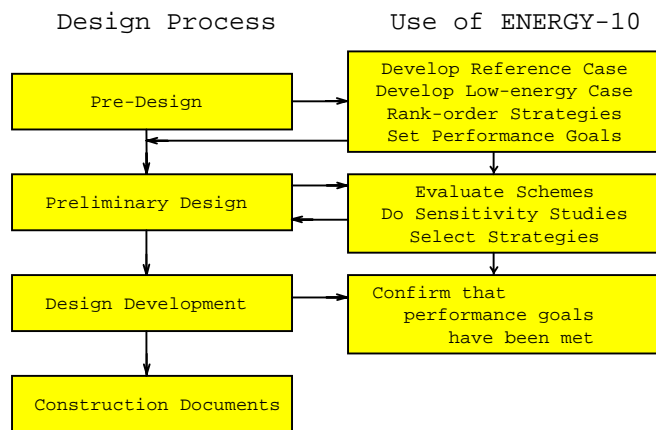
(2) Energy efficiency must be designed in from the start—beginning in pre-design and particularly during the preliminary design phase. Traditional detailed evaluation tools, such as the large thermal and daylighting simulation programs, are not suitable. Because existing tools are so difficult to use, they have been employed late in the design process—when it is too late to affect the result.

(3) Simplified tools, while appropriate for most conventional buildings, tend to fall short when used to analyze high performance buildings. As one stretches the envelope, this becomes more and more the case.

ENERGY-10 and its associated guidelines book, *Designing Low-Energy Buildings*, have been designed to solve this dilemma. The user sees

the impact of design changes on potential savings in total energy and operating cost *from the beginning*. The program enables the user to select passive solar, improved insulation, and other features to create a design that inherently requires minimum backup. Selecting highly efficient heating and cooling equipment completes the process, leading to a building that minimizes annual energy, annual operating cost, or life-cycle cost.

The following diagram shows how *ENERGY-10* complements the traditional architectural design process.

```
Design Process          Use of ENERGY-10

                      ┌──────────────────────────┐
┌──────────────────┐  │  Develop Reference Case  │
│    Pre-Design    │──▶│ Develop Low-energy Case  │
└──────────────────┘  │   Rank-order Strategies  │
         │  ◀──────── │   Set Performance Goals  │
         ▼            └──────────────────────────┘
┌──────────────────┐  ┌──────────────────────────┐
│Preliminary Design│──▶│    Evaluate Schemes      │
└──────────────────┘  │  Do Sensitivity Studies  │
         │  ◀──────── │   Select Strategies      │
         ▼            └──────────────────────────┘
┌──────────────────┐  ┌──────────────────────────┐
│Design Development│──▶│  Confirm that            │
└──────────────────┘  │    performance goals     │
         │            │      have been met       │
         ▼            └──────────────────────────┘
┌──────────────────┐
│Construction Documents│
└──────────────────┘
```

ENERGY-10 automatically sets up of two building descriptions based on only five key characteristics—information that is known in pre-design. It then automates the process of both applying and rank ordering a variety of energy efficiency and passive solar measures. It integrates thermal issues with the daylighting issues in a package that gives preliminary results even before the building is designed. It emphasizes the use of passive solar measures including daylighting, passive solar heating, and ventilation cooling as design options to be integrated with efficient equipment and shell designs.

FEATURES OF *ENERGY-10*

AutoBuild. In the pre-design phase, two complete building descriptions are generated automatically. These are a *Reference Case* and a *Low-Energy Case.* The *Reference Case* is a basic shoe-box building that satisfies the building requirements. The *Low-Energy Case* is the same building but modified to incorporate a set of energy-efficient strategies (EESs) pre-selected by the user. These two simulated buildings give the designer two important pieces of information: (1) They show the energy use pattern of a typical building of the right size, in the right climate, having the appropriate internal-gains for a building of the desired type. The balance between heating, cooling, and other energy uses is determined. (2) The simulations identify the potential for energy and cost savings from a particular set of strategies. About 15 minutes after starting a new project, the user can be studying the results (see bar chart, next page).

Only five inputs (location, size, use, HVAC, and number of stories) are needed to initiate the AutoBuild process (menu shown above). With this information, the program creates a provisional shoe-box building description. The user can fine-tune the dimensions or other features or simply accept the program's suggestions. Using a default library, the program then proceeds to generate a complete building description of the that includes hundreds of design parameters. The *Low-Energy Case* is

then created by performing an APPLY operation (described later) to the *Reference Case* using a default set of energy-efficient strategies.

The general principle used in *ENERGY-10* is that everything is defaulted, but everything can be changed. For example, when the user selects a building use category (office mercantile and service, restaurant, grocery, warehouse, assembly, education, lodging, or residential) the program selects hourly profiles of internal heat generation caused by lights, people, hot water, and "other" that match measured data and yield national-average end-use energy consumption values appropriate for the desired type of building. Subsequently, the user can easily change either the individual profiles or the peak values.

2400 sf House in Minneapolis / AutoBuild Shoebox
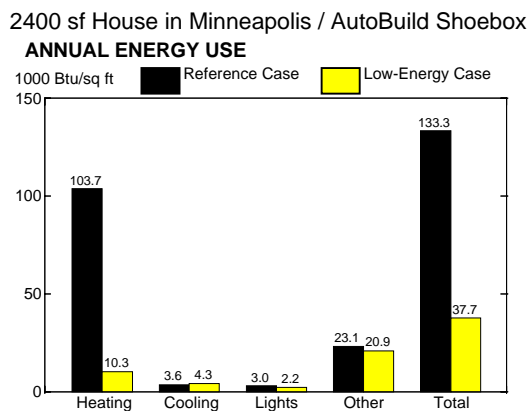
Annual Results of AutoBuild Buildings

The bar chart shows the result of the AutoBuild process, taking only about ten minutes, start to finish on a Pentium computer. Operating costs can also be graphed. The two houses are described on the *Summary Page* at the end of the paper. The Summary Page is a feature of *ENERGY-10*, and, like the bar chart, was cut and pasted into this paper.

The power of AutoBuild is that things that can be automated are automated, saving the user time. This comes at no loss of flexibility,

however, because all defaults are accessible and can be adjusted. The amount of intervention required to create a realistic building description depends on where the user is in the design process. Early on, in pre-design, a rough geometrical approximation of the building is suitable because there is no actual design to describe. Later, when the design has solidified, the geometrical details can be entered.

APPLY. With a few mouse clicks, the user can globally change the building description. There are 10 EESs to choose from in *ENERGY-10*. The user first selects any set of desired EESs from a menu and then clicks on APPLY. The program recreates a complete new building description by modifying the *Reference Case* according to a prescription. For example, if the *Insulation EES* is selected, all of the walls in the building might be changed to 6-in SIP construction, the roof changed to R-60, and the perimeter insulated with 2 inches of foam. The user gets to specify exactly what changes will be made. The 10 EESs are:

Insulation	Glazing
Passive Solar Heating	Thermal Mass
Shading	Daylighting
High Efficiency HVAC	Economizer Cycle
Energy-Efficient Lights	HVAC Controls

The APPLY operation was actually used to generate the *Low-Energy Case* in the previous example, starting with the default *Reference Case*. Eight of the possible strategies were applied, excluding daylighting (because it is already included in the default lighting schedule for residential buildings) and economizer cycle. The combined effect of the strategies is evident in the bar charts, comparing the results for the two buildings.

RANK. This feature is similar to APPLY except that the EESs are applied individually. When the

user selects a set of EESs and then clicks on RANK, the program applies the first EES, performs a simulation, saves the results, removes the EES, applies the next EES, and so forth until all the EESs have been applied and simulated. The program then rank-orders the results according to the desired criteria (lowest annual energy, lowest annual operating cost, lowest life-cycle cost, etc.) and displays the result, which might appear as shown below.

With the use of these features—AutoBuild, APPLY, and RANK—the user can spend less than an hour during pre-design and be well equipped to begin design, knowing which strategies should be investigated as the design proceeds. The designer can present these initial results to the client, and the two parties can agree on energy-performance goals for the building.

Graphic Output. Twenty graphic outputs are available in fixed formats, generally comparing the current design with a reference building. Bar graphs, such as the above example, compare overall loads, costs, and cost breakdown by end use. Line graphs, such as the example below, show monthly loads, average-daily monthly profiles, daylighting effectiveness, and actual hourly results for any period. Bar-graph comparisons of a selected sequence of design schemes can be displayed (using KEEP, another time-saving feature of *ENERGY-10*). All graphical results can be printed directly or exported as metafiles for inclusion in a report. This feature was used in the writing of this paper—all of the graphs were copied directly from *ENERGY-10* and then edited slightly for style. These graphs can be used to educate the client and to demonstrate the value of good building design.

2400 sf House in Minneapolis
Low-Energy Case
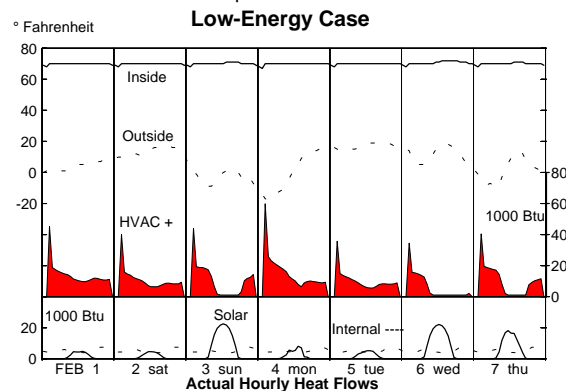
Example of Hourly Simulation Results

2400 sf House in Minneapolis
ANNUAL COST BREAKDOWN

Example of Cost Breakdown Graph
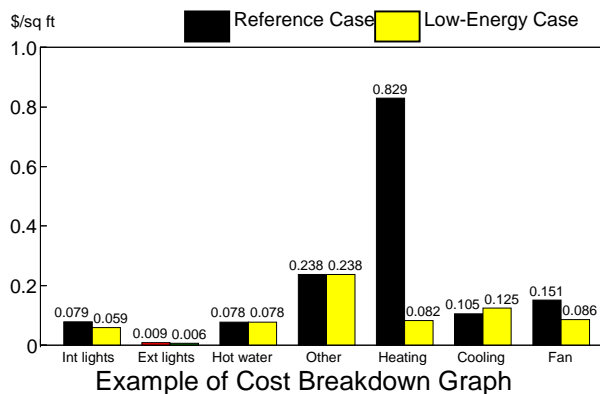
Other features include a library of materials, constructions, and schedules that can be added to or modified on the fly.

EVOLVING THE BUILDING DESCRIPTION

As the building proceeds from pre-design into preliminary design, the building description in *ENERGY-10* must be modified to represent the various schemes being considered. This is done by editing the initial *Low-Energy Case* generated by AutoBuild. The graphical user interface in *ENERGY-10* makes this process both fast and intuitive. The APPLY feature and RANK features can be used at any point to evaluate global changes, as described above. Other changes, such as modifications in the building take-offs, can be made by simply editing values, such as the area of a particular

wall, in the appropriate menu. As the design proceeds, the building descriptions become more and more detailed and become more and more representative of the building being designed and less like the original shoe-box created by AutoBuild.

At each stage of the design, a new simulation can be performed to check progress. The results of the design evolution can be easily documented using the KEEP feature.

At the end of preliminary design, when others might be just thinking about doing their first simulation analysis, the user of ENERGY-10 is nearly finished, confident that the building will be energy-efficient.

USE IN RETROFIT SITUATIONS

ENERGY-10 is very suitable for use in retrofit as well as new construction. The user enters the existing building as the *Reference Case* and then investigates the effect of various retrofit strategies by applying these strategies to create the *Low-Energy Case*. Simulation results are displayed side-by-side to facilitate comparison. The RANK feature is equally useful.

WORKSHOPS AND TRAINING

ENERGY-10 is the software component of an overall Building Guidelines project funded by the U.S. Department of Energy that is being carried out by the Passive Solar Industries Council (PSIC) and the National Renewable Energy Laboratory. A guidelines book, *Designing Low-Energy Buildings*, has been developed by PSIC that is designed to be used in a workshop environment in conjunction with the ENERGY-10 program. PSIC is conducting these workshops both nationally and locally to help designers understand the issues of energy efficiency and provide them with a suitable analysis tool.

WHERE *ENERGY-10* FITS IN TO THE PICTURE

The precursor to *Energy-10* is the set of residential guidelines that have been distributed by PSIC for several years. The guidelines consist of a book, *Passive Solar Design Strategies: Guidelines for Home Builders* and the accompanying *BuilderGuide* computer program. These guidelines have been written for about 200 locations (out of nearly 3000 potential locations) and one-day workshops presented in about 70 locations to a combined audience of nearly 3000 attendees.

Designing Low-Energy Buildings is a follow-on to residential guidelines and its associated *BuilderGuide* design tool. The format of the previous residential guidelines and the new guidelines is similar, but the ENERGY-10 is based on hourly simulation whereas *BuilderGuide* is based on simplified methods. ENERGY-10 is much more powerful but somewhat harder to use; *BuilderGuide* is very simple and easy to use but provides correspondingly less information and is able to cope with a smaller range of issues and building types. Each program has its place in the residential picture.

ENERGY-10 addresses both residential buildings and the 76% of all commercial buildings under 10,000 sq ft that comprise 22% of the total non-residential floor area. These smaller buildings tend to be quite energy intensive but are particularly amenable to passive design strategies. This tool is targeted at the small firms that usually design these buildings. ENERGY-10 is also designed to be suitable for use in planning and implementing utility demand-side management programs.

THE SIMULATION ENGINES

Thermal analysis uses the California Non-Residential Simulation Engine (CNE) written by the Berkeley Solar Group, which employs a multi-zone, thermal-network solution (Wilcox et al, 1992). Despite the name, CNE is highly suitable for evaluating residential buildings. *ENERGY-10* has been validated using the BESTEST protocol now adopted by the Department of Energy. The daylighting analysis engine , which was written by the Lawrence Berkeley Laboratory, incorporates the split-flux routine used in the DOE-2 computer program.

ENERGY-10 automatically transfers a description of the building to the thermal simulation engine. Conversion from design specification to simulation conditions is part of this process. The simulator transforms the building description into a thermal network model. The thermal network solver uses ¼-hour time steps and iterates to find an energy balance between the loads and system at every time step. A rigorously enforced energy balance is important for accurate simulation of highly interactive EESs used in good passive design.
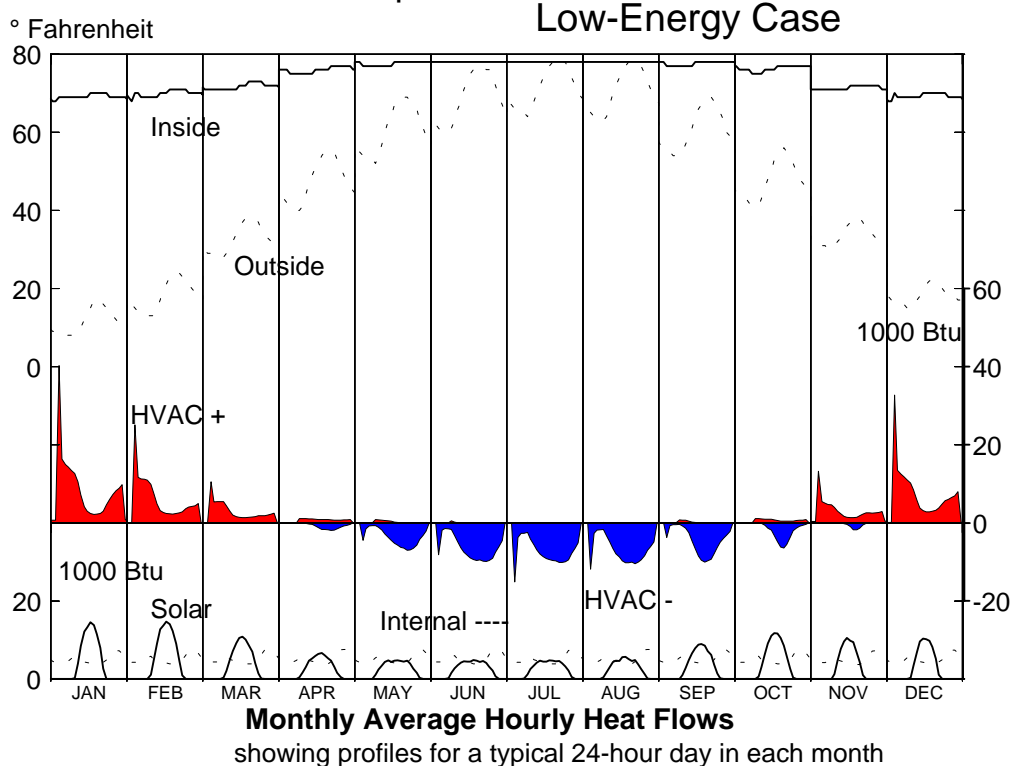
COMPUTER PLATFORM

ENERGY-10 operates under Microsoft Windows. All routines are written in the C language (Visual C++, etc.). A 486 processor or higher is recommended with 16 MB of RAM. A 32-bit operating system is highly recommended. With this equipment, a pair of annual simulations, including one daylighting simulation requires 12 minutes to complete on a 486 machine running at 66 megahertz. This goes *much* faster with a fast Pentium processor and takes only *23 seconds* on a Pentium Pro.

ENERGY GRAPHICS

A very useful concept called "Energy Graphics" was developed in the late 1970s by the architectural firm of Burt Hill Kosar Rittleman.

2400 sf House in Minneapolis
Low-Energy Case

Monthly Average Hourly Heat Flows
showing profiles for a typical 24-hour day in each month

The general idea was to make a 24-hour plot of the performance of a building for a typical day in each of the four seasons. These plots showed the major energy flows of the building including internal gains, heat loss or gain through the envelope, solar gains, and the required heating and cooling. Because computing tools were limited at that time, the values were usually determined using approximations and simple rules. Despite its limitations, the tool was widely acclaimed by energy-conscious designers because it showed the basic energy characteristics of the building in a compact and readily understood format.

The energy-graphics concept was borrowed to define the format of three plots in ENERGY-10. Each of these graphs plots several important parameters through an average day for each month of the year. The values are derived from the hourly simulation results. One graph shows heat flows, as in the original energy graphics; the second plots energy into the HVAC system; and the third shows savings from daylighting. An example of the heat-flow graph is shown on the previous page. Taken together, the three graphs provide a comprehensive view of the building's hourly *and* month-by-month behavior in a compact format.

Of course, the user can also study graphs of the actual hourly behavior. The graphics controls make it very simple to find and focus in on peak heating or cooling conditions, to jump to any desired time period, or to show from 1 up to 14 days on a plot.

CONCLUSION

Passive design techniques have proved to be effective in *greatly* reducing energy and operating costs of buildings at little, if any, increase in construction cost (Burt Hill Kosar Rittleman, 1987). The buildings are comfortable and quiet. Passive buildings are reliable because they operate by natural means. They are constructed using traditional building elements—wood, glass, masonry, insulation, concrete, and steel—and are thus easily understood by the occupants and easily maintained by local trades people using locally available materials. Passive design approaches work well with mechanical systems usually resulting in down-sizing of the equipment.

Successfully integrating passive solar heating, natural cooling, daylighting, efficient shell design, and efficient equipment requires a systematic approach applied throughout the design process.

Conflicts between the need for solar heat in the winter, avoiding solar heat in the summer, and sufficient natural light can be resolved through design elements, but it careful analysis is required to strike the proper balance (Balcomb, 1994).

ENERGY-10 allows the designer to easily evaluate the saving potential and cost effectiveness of 10 of the most effective passive and energy-efficiency strategies before design begins. It is also suitable for evaluating various schemes in schematic design and for showing compliance with quantitative energy performance design goals at the end of the design process.

AVAILABILITY

ENERGY-10 was released in June 1996. It is available from the Passive Solar Industries Council, 1511K St. NW, Washington, DC, (202-628-7400) who provide user support and also organize the two-day workshops.

ACKNOWLEDGMENTS

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Burt Hill Kosar Rittleman and Min Kantrowitz Associates, *Commercial Building Design: Integrating Climate, Comfort and Cost*, Van Nostrand Reinhold Co. New York (1987).

Wilcox, B. A., J. R. Barnaby, and P. W. Niles, *CNE Users Manual*, Berkeley Solar Group, Oakland, CA (1992).
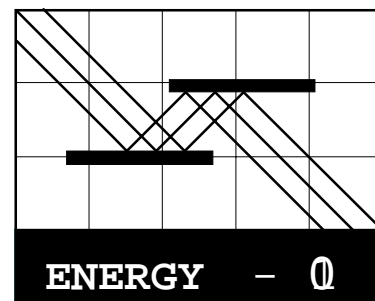
SUMMARY PAGE

A *Summary Page* shows in the background of *Energy-10* at all times. It is a synopsis of the building description. The *Summary Page* for the example house in Minneapolis, for which results have been shown earlier, is reported on the following page.

Summary Page: 2400 sf House in Minneapolis — Variant: AutoBuild Shoebox
(ventilation and infiltration of the LEC were reduced after AutoBuild)

Description:	Reference Case	Low-Energy Case
Floor Area	2400	2400
Surface Area	6600	6600
Volume	21600	21600
Surface Area Ratio	1.42	1.42
Total UA	524.6	205.7
Average U-value	0.079	0.031
Wall Construction	2 x 4 frame, R=12.6	6 in SIP, R=22.4
Roof Construction	flat, r-19, R=19.0	attic, r-60, R=60.2
Floor type, insulation	Slab on Grade, Reff=13.3	Slab on Grade, Reff=60.0
Window Construction	3040 double, wood, U=0.47	3040 super, wood, U=0.19,etc
Window Shading	None	44 deg latitude
Wall total gross area, sf	1800	1800
Roof total gross area, sf	2400	2400
Ground floor gross area, sf	2400	2400
Window gross area, sf	192	312
Windows (N/E/S/W:Roof)	5/3/5/3:0	5/2/17/2:0
Glazing name	double, U=0.49	quad low-e 88, U=0.12
Infiltration effective leakage area, sq in	240	60
HVAC system	DX Cooling with Gas Furnace	DX Cooling with Gas Furnace
Heating thermostat	70 F, no setback	70 F, setback to 65 F
Cooling thermostat	78 F, no setup	78 F, setup to 83 F
Heat/cool performance	eff=80,EER=8.9	eff=90,EER=13.0
Economizer?/type	no/NA	no/NA
Duct leakages, total %	21	3
Peak Gains, W/sf	0.20/0.04/0.66/0.36	0.15/0.03/0.66/0.36
Added mass?	none	1200 sf, 8in cmu
Outside forced ventilation?	none	none
Results:	(Energy cost: $0.80/therm, $0.10/kWh)	
Simulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec
Simulation status	valid/NA	valid/NA
Energy use, kBtu	319960	134078
Energy cost, $	3575	1908
Saved by daylighting, kWh	NA	NA
Internal/External lights, kWh	1886/206	1414/154
Hot water/Other, kWh	6880/5717	6880/5717
Heating/Cooling/Fan, kWh	0/2526/3636	0/2114/2097
Total Electric, kWh	13970	11496
Peak electric, kW	6	5
Fuel, million Btu	272	95